PROTON AND PION FLUXES FROM THE MICE BEAMLINE PRELIMINARY MEASUREMENTS & SIMULATIONS

D. Huang, Illinois Institute of Technology. Chicago, IL 60616, USA
A. Blondel, J. S. Graulich, DPNC University of Geneva, CH1205, Switzerland
K. Tilley, Rutherford Appleton Laboratory, UK
V. Palladino, INFN-Napoli, Italy

INTRODUCTION

In order to better understand the MICE beamline and particle spectrum, , it is useful to measure the proton and pion rates as a function of momentum. Our experiment involved adjusting the strengths of the quadrupole magnets Q1, Q2, Q3, at a fixed primary momentum and dipole field D1 to maximise the flux. Once these are fixed, the dipole 2 can be adjusted as a spectrometer. The protons and pions, identified by the Time Of Flight (TOF) between the counters GVA1 and GVA2, can be seen to separate thanks to their different energy loss in the material present between D1 and D2.

A point of interest is the momentum at which protons cease to be transmitted to GVA2, as this is a sensitive measure of the material in the beam line. G4beamline simulations had been prepared to this effect. Measurements were then performed by scaling the upstream and downstream magnet currents to different momenta. In this note, some outputs of G4beamline are presented and compared with the measurements.

These measurements were performed during the MICE operation on July 14 – 15, 2008. Primary momenta in B1 between ~321 and 476 MeV/c (see Appendix 3) were investigated

G4BEAMLINE SIMULATION

For the G4beamline simulation, the latest version of 1.14b is employed. The input deck is based ontheMICE stage 0 layout in July 2008 [see ref1]. The input proton momentum is the momentum of the reference proton right after the target. In the simulation, the strength of the bending magnets B1 and B2 are adjusted by G4Beamline itself to obtain the best proton acceptance at B1 and B2. As a preliminary work, Q1-Q3 are also turned off for simplicity.

The total input number of proton events is fixed at 5.2×10^9; the proton momentum off target is scanned to output the total number of events at detector GVA1(which is after the decay solenoid),and GVA2 (which is after the quadrupole Q6) - see Figure 1. The layout of the present MICE beamline is the following:

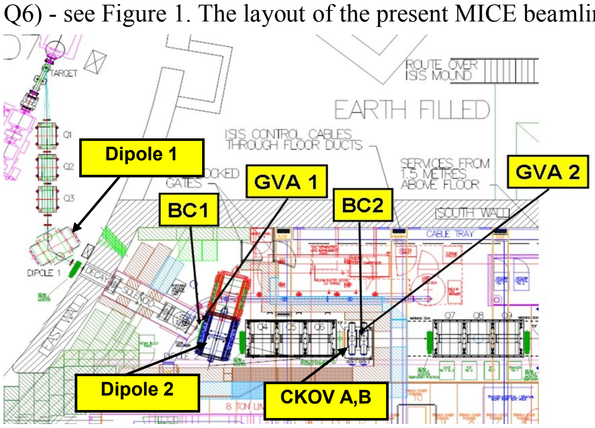

Figure 1: Layout of the MICE components in July, 2008

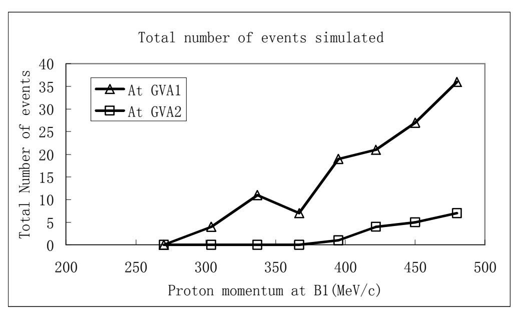

Figure 2: Total number of events at detector GVA1 and GVA2 by G4Beamline simulation as a function of proton momentum at dipole magnet B1

After a few runs, we have the curves of the total number of events at detector GVA1 and GVA2 as a function of initial proton momentum. The proton energy was scanned from 325 MeV/c - 504MeV/c, corresponding to ~268MeV/c – 477 MeV/c (see Appendix 2) at the B1 magnet. The curves are illustrated in Figure 2.

In Figure 2, one can see that below ~268MeV/c, the total number of events at GVA1 goes to zero, and below ~ 363 MeV/c, the total number of events at GVA2 goes to zero. [the figure needs to be updated slightly thus]

MEASUREMENTS

In order to compare with the G4Beamline simulation, detailed measurements were done during the shift on July 14-15 2008. The target was operated following the documentation. The target was dipped so as to produce ISIS beam loss monitor readings of less than 50mV. The data acquisition gate was 2ms and adjusted to the end of the ISIS spill. Each measurement corresponds to 120 successive spills. An absolute normalization is not possible at this point due to variation of the target and ISIS beam interception. In absence of recording of the ISIS BLMs, the relative normalization between recordings is only as good as the reproducibility of the target interaction with the ISIS beam over the 120 spill acquisition period. A repeat measurement with the beamline same settings during the evening showed variation between 8100 and 8800 hits in GVA1. Potentially the variation could be larger, particular over longer time periods as the ISIS beam varies. A device measuring directly pion production in the vicinity of the target in the vault for absolute normalization would be rather useful.

The particle production was measured in the counters GVA1 and GVA2. Backgrounds during the beam gate were small and can be neglected for the results presented here. The measurements are tabulated in Table 1 at the end of this note. The data were recorded by the MICE data acquisition as run numbers 402 to 436. The histogram presented in Figure 3 and the numbers appearing in the table were recorded by the DAQ monitoring online. No offline analysis has been performed on these data.

First of all, at a B1 current of 400Amps, corresponding to momentum ~476 MeV/c , the strengths of the quadrupoles Q1, Q2 and Q3 were set at their nominal values, and then varied by ±20% to seek better rates. No scan of D2 was performed at that energy, at which the number of protons was about 20 times larger than that of pions. In these measurements, the quadrupoles Q4, Q5 and Q6 were turned off. An increase of nearly 40% in particle intensity was then seen by either raising the excitation of quadrupoles Q1 and Q3 by 20% over their nominal 480MeV/c values, or by raising Q1 alone by 20%. The later setting was chosen as the basis for further work.

It should be emphasized that this can hardly be considered to be an full optimization procedure, and this process will be developed further in due course. ..

We then proceeded to perform the measurements for an upstream momentum of ~414 MeV/c (I=333A), ~374 MeV/c (I=291A) and ~322 MeV/c (I=250A)c. Unfortunately, as the B1 field had a strong nonlinear dependence on current, and having scaled all magnet currents Q1-3 & B1 linearly, the Q1-Q3 settings corresponded to a slightly lower momentum by ~10%, but the results are nevertheless acceptable for the current experiment: gaining a first understanding of proton/pion energy dependence. At these momenta, the dipole magnet B2 strength was scanned and the pion and proton productions were measured. Particle production was measured with the GVA1 and GVA2 counters. Pion and proton productions were identified by the time-of–flight between GVA1 and GVA2. Two peaks corresponding to pions and protons can be observed, as illustrated in Figure 3. The measurements are summarized in Appendix 1 at the end of the note.

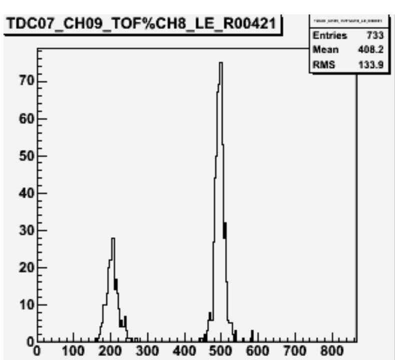

Figure 3: The pion and proton separated through the time-of-flight between GVA1 and GVA2. The left peak consists of pions, and the right peak of protons

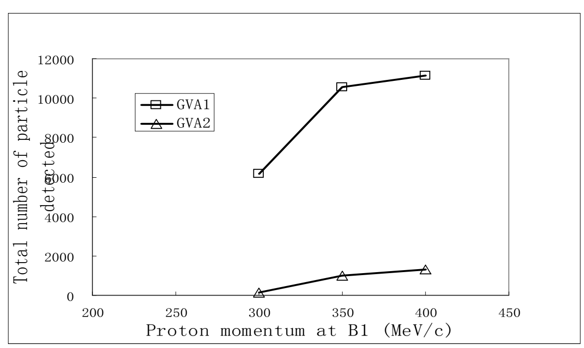

Figure 4: Total number of events at GVA1 and GVA2 as a function of momentum in the dipole magnet B1 Q: check what does this graph show? Total # at proton peak? If so it = G4BL.

The total number of events at GVA1 and GVA2 as a function of momentum at B1 are plotted in the Figure 4. It decreases with proton momentum and this is consistent with the G4Beamline simulation. It can be observed that experimentally, the cut off momentum for particles in GVA2 is ~321 MeV/c, whilst from the simulation, it appears to be ~363MeV/c.

The following figures illustrate the pion and proton production rates normalised to the total number of events at GVA1, as a function of the current in dipole magnet B2. Figure 5 is for ~414 MeV/c momentum at B1; Figure 6 for ~374 MeV/c proton momentum; and Figure 7 for ~ 321 MeV/c proton momentum, respectively.

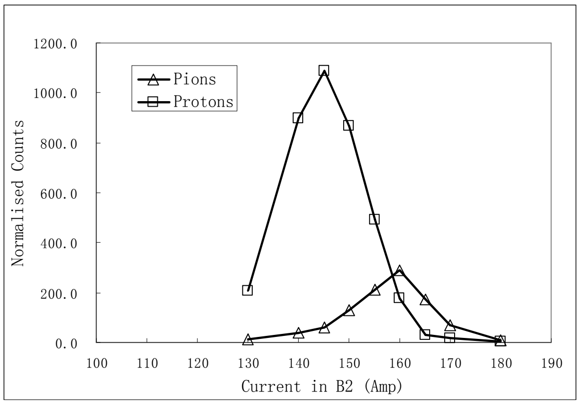

Figure 5: Pion and proton production rates as a function of current in dipole magnetic B2 at414 MeV/c proton momentum at B1, normalised to the total counts at GVA1

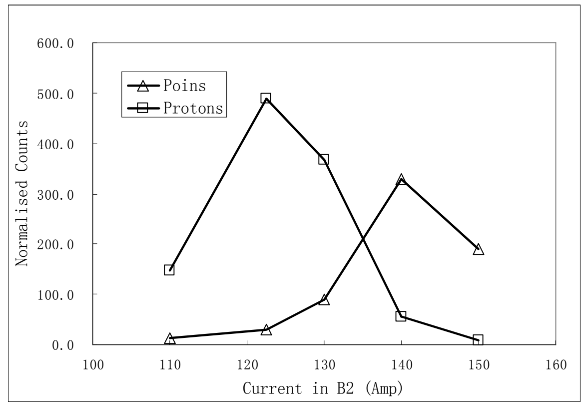

Figure 6: Pion and proton production rates as a function of current in dipole magnetic B2 at 373 MeV/c proton momentum at B1, normalised to the total counts at GVA1

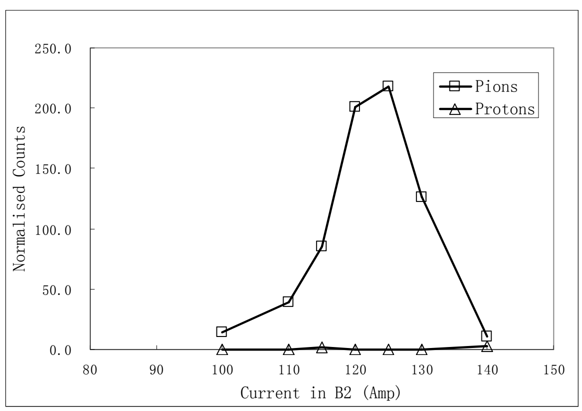

Figure 7: Pion and proton production rates as a function of current in dipole magnetic B2 at ~321 MeV/c momentum at B1, normalised to the total counts at GVA1

In the figures above, one can see that as decreasing the momentum at B1, the proton production gets smaller and smaller. At ~ 321MeV/c, the measured proton rate goes to zero.

CONCLUSIONS

We have measured relative proton and pion rates in the MICE beam line at ~321MeV/c, 374 and 414 MeV/c. As expected, proton production drops drastically when decreasing momentum and has all but disappeared at ~321 MeV/c. With this particular layout of detectors, a good setting was established at ~321 MeV/c for producing a pure positive pion beam for further studies.

The results seem to be consistent with simulation although a measurement with finer momentum steps would be desirable. G4 beamline seems to indicate that already at ~363 MeV/c protons should not reach GVA2 which is somewhat discrepant with the measurements. A number of effects could account for this. A closer examination of the momenta estimate in B1 from both simulation and measurement would be useful, as well as for a closer inspection of the G4Beamline deck file modelling the beamline. Closer study of how it sets the B2 magnet would be of interest. G4beamline is a useful tool to help MICE commissioning and study. It would be great if it were installed in such a way as to be available from the MICE control room for MICE shifters inexperienced in its use to simulate beam settings while (or preferably before!) taking data.

The relatively limited data statistics and the long time it takes to accumulate them highlight the need for intersecting more protons with the target. Including the ISIS BLM readings in the MICE data stream is necessary for absolute normalization and will be essential to performing closer optimization of the upstream beamline. Further measurements will be needed to measure and optimize pion intensity in the upstream MICE beam line.

References

1.G4Beamline model used for simulations:-
http://www.isis.rl.ac.uk/accelerator/MICE/Task%20Notes%20and%20Specifications/beamline%20-%20optics/G4BL_April4_ProtonBLModelupdate160708.htm

2. Current to Field Relationship for B1:
http://www.isis.rl.ac.uk/accelerator/MICE/Task%20Notes%20and%20Specifications/beamline%20-%20optics/Data/M1-6inchtapered.ppt

Appendix 1: tabulation of measurements performed on July 14-15 2008.

Change the following table so that Momentum in column1 is our corrected estimate (ie 300->321MeV/c etc etc):-

Momentum (MeV/c)	run #	Q1	Q2	Q3	D1	D1 Set	Q4	Q5	Q6	D2	D2 Set	GVA1	Sigma GVA1	GVA2	PION	PROTON	PION /GVA1	PROT /GVA1
480	402	104.4	191.0	117.0	400.0	800.0	0	0	0	170	850	8947	95	2984	93	1599		
480	403	83.5	152.8	93.6	400.0	800.0	0	0	0	170	850	5976	77	1779	59	1049		
480	404	104.4	191.0	140.4	400.0	800.0	0	0	0	170	850	11683	108	3665	98	1753		
480	405	125.2	191.0	117.0	400.0	800.0	0	0	0	170	850	12560	112	4073	107	1950		
480	406	104.4	191.0	93.6	400.0	800.0	0	0	0	170	850	6916	83	2288	86	1303		
480	407	104.4	152.8	117.0	400.0	800.0	0	0	0	170	850	8290	91	2378	70	1317		
480	408	83.5	191.0	117.0	400.0	800.0	0	0	0	170	850	6713	82	2328	77	1392		
480	409	125.2	191.0	140.4	400.0	800.0	0	0	0	170	850	13138	115	3984	98	1859		
480	410	104.4	191.0	117.0	400.0	800.0	0	0	0	170	850	8231	91	2699	85	1561		
400	412	104.4	159.2	97.5	333.3	666.7	0	0	0	170	850	14081	119	228	89	22	63.2	15.6
400	413	104.4	159.2	97.5	333.3	666.7	0	0	0	150	750	13397	116	2969	156	1043	116.4	778.5
400	414	104.4	159.2	97.5	333.3	666.7	0	0	0	140	700	11477	107	2464	41	923	35.7	804.2
400	415	104.4	159.2	97.5	333.3	666.7	0	0	0	160	800	10435	102	798	270	167	258.7	160.0
400	416	104.4	159.2	97.5	333.3	666.7	0	0	0	130	650	11167	106	768	13	207	11.6	185.4
400	419	104.4	159.2	97.5	333.3	666.7	0	0	0	180	900	3686	61	11	3	2	8.1	5.4
400	420	104.4	159.2	97.5	333.3	666.7	0	0	0	145	725	10007	100	2471	55	978	55.0	977.3
400	421	104.4	159.2	97.5	333.3	666.7	0	0	0	155	775	11463	107	1646	218	508	190.2	443.2
400	422	104.4	159.2	97.5	333.3	666.7	0	0	0	165	825	14621	121	551	225	39	153.9	26.7
350	423	91.3	139.3	85.3	291.7	583.3	0	0	0	122.5	612.5	12204	110.472	2230	35	567	28.7	464.6
350	424	91.3	139.3	85.3	291.667	583.3	0	0	0	140	700	10769	103.774	713	336	56	312.0	52.0
350	425	91.3	139.3	85.3	291.667	583.3	0	0	0	150	750	10140	100.698	290	183	9	180.5	8.9
350	427	91.3	139.3	85.3	291.667	583.3	0	0	0	110	550	9665	98.3107	416	12	135	12.4	139.7
350	428	91.3	139.3	85.3	291.667	583.3	0	0	0	130	650	9945	99.7246	1341	84	347	84.5	348.9
300	429	78.3	119.4	73.1	250	500.0	0	0	0	100	500	7202	84.8646	33	17	0	23.6	0.0
300	430	78.27	119.37	73.122	250	500	0	0	0	110	550	6736	82.0731	63	43	0	63.8	0.0
300	431	78.27	119.37	73.122	250	500	0	0	0	120	600	7153	84.5754	348	234	0	327.1	0.0
300	432	78.27	119.37	73.122	250	500	0	0	0	130	650	6947	83.3487	186	143	0	205.8	0.0
300	433	78.27	119.37	73.122	250	500	0	0	0	140	700	7167	84.6581	21	12	3	16.7	4.2
300	434	78.27	119.37	73.122	250	500	0	0	0	115	575	3721	61	73	52	1	139.7	2.7
300	436	78.27	119.37	73.122	250	500	0	0	0	125	625	4051	63.6475	209	144	0	355.5	0.0

Appendix 2. Conversion of G4Beamline simulations into Momenta in B1

G4Beamline operates by selecting an initial scattered proton momentum just after the target. Its momentum in B1 can be extracted either directly, or by extracting the B1 field and using its corresponding effective length. The effective length was taken to be the handbook value of 1.038m, hence 1.087m for a particle bending by 60degrees in a homogenous field. Further improvement could be made by evaluating the effective length of the field map used in G4BL.

The conversion is given below:-

P (Target MeV/c)	B1 Field (T)	p estimate in B1 (MeV/c)
504	1.5331	477.4

475	1.4376	447.7
450	1.3487	420.0
425	1.2625	393.1
400	1.1683	363.8
375	1.0765	335.2
350	0.9717	302.6
325	0.8632	268.8

Appendix 3. Conversion of Experimental Settings of B1 to Momenta in B1

The conversion from a current in B1 to the momenta in B1 is effected by using the handbook current to field graph. [2], together with the handbook effective length of 1.038m, and hence 1.087m in the curved trajectory.

The conversion is given below:-

B1 current (Amps)	p estimate in B1 (MeV/c)
400.0	476.4
333.3	414.2
291.7	373.7
250.0	320.7